Ocean Nowcast/Forecast Systems for Naval Undersea Capability

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Abstract

The U.S. Navy is a major investor in ocean model development. The pay-off of such an investment is the value-added ocean nowcast/forecast systems on the naval operations and warfare effectiveness. The purpose of this paper is to investigate the value-added of the Navy's nowcast/forecast system to the naval antisubmarine warfare (ASW) and anti-surface warfare (ASUW). The nowcast/forecast versus observational fields were used by the Weapon Acoustic Preset Program (WAPP) to determine the suggested presets for Mk 48 variant torpedo. The metric used to compare the two sets of outputs is the relative difference in acoustic coverage area generated by WAPP. Output presets are created for five different scenarios, two ASUW scenarios and three ASW scenarios in the South China Sea. The same metrics used in the nowcast/forecast case were used to generate and compare the acoustic coverage. Analysis of the output reveals that the ocean forecast system outperformed the nowcast system in most scenarios.

1. Introduction

Understanding the ocean environment is imperative and directly coupled to the successful performance of undersea sensors and subsequent employment of undersea warfare weapon systems. In order to optimize the performance of undersea sensors and weapons systems, it is crucial to gain an understanding of the acoustic wave propagation in the ocean. Having an accurate depiction of the ocean environment is therefore directly related to gaining a better understanding of the acoustic wave propagation.

How acoustic waves propagate from one to another location undersea is determined by many factors, some of which are described by the sound speed profile (SSP). If the environmental properties of temperature and salinity are known over the entire depth, the SSP can be calculated. Two approaches are used to increase the accuracy of ocean temperature and salinity depiction: (1) satellite data assimilation, and (2) ocean nowcast/forecast systems. Chu et al. (2004a, 2006) show the importance of the satellite data assimilation for improvement of the naval undersea capability.

The U.S. Navy has developed ocean nowcast/forecast systems to determine or to predict representative SSP. For example, Modular Ocean Data Assimilation System (MODAS) is a commonly used nowcast system, which is built on the base of the optimal interpolation (statistical model). The Navy Coastal Ocean Model (NCOM) is a commonly used ocean forecast system, which is built on the base of the Princeton Ocean Model (POM). MODAS uses climatology as the initial guess and assimilates satellite and in-situ measurements such as altimetry, conductivity-temperature-depth (CTD), expendable

bathythermographs (XBT), and ARGO casts. NCOM (physical model) forecasts the ocean environment using observational data such as temperature, salinity, and velocity.

Representation of the Navy's nowcast (MODAS) and forecast (POM) systems for ocean environment (SSP through T, S profiles) was verified using the CTD data collected from the South China Sea Monsoon Experiment (SCSMEX) in April – June 1998 (Chu et al., 2001, 2004b). The errors have a Gaussian-type distribution with mean temperature nearly zero and mean salinity of -0.2 ppt. However, evaluation of value-added ocean nowcast/forecast system on the naval undersea capability has yet been conducted. At the combat level, acoustic detection of torpedo is extremely important for the undersea warfare. In this study, the Weapon Acoustic Preset Program (WAPP) for Mk-48 torpedo is used for such an evaluation.

2. Oceanographic Observations

2.1. South China Sea

The South China Sea (SCS) is a semi-enclosed tropical sea located between the Asian land mass to the north and west, the Philippine Islands to the east, Borneo to the southeast, and Indonesia to the south (Figure 1), covering a total area of 3.5×10^6 km^2. It includes the shallow Gulf of Thailand and connections to the East China Sea (through Taiwan Strait), the Pacific Ocean (through Luzon Strait), Sulu Sea, Java Sea (through Gasper and Karimata Straits) and to the Indian Ocean (through the Strait of Malacca). All of these straits are shallow except Luzon Strait, the maximum depth of which is 1800 m. The complex topography includes a broad, shallow shelf in the south/southwest; the continental shelf of the Asian landmass in the north, extending from the Gulf of Tonkin to Taiwan Strait; a deep, elliptical shaped basin in the center, and numerous reef islands

and underwater plateaus scattered throughout. The shelf that extends from the Gulf of Tonkin to the Taiwan Strait is consistently nearly 70 m deep, averaging 150 km in width; the central deep basin is 1900 km along its major axis (northeast-southwest) and approximately 1100 km along its minor axis, extending to over 4000 m deep. The south/southwest SCS shelf is the submerged connection between southeastern Asia, Malaysia, Sumatra, Java, and Borneo and reaches 100 m depth in the middle; the center of the Gulf of Thailand is about 70 m deep.

2.2. South China Sea Monsoon Experiment

SCSMEX was a multi-national large scale experiment (intensive observational period: April to June 1998) to study the water and energy cycles of the Asian monsoon regions with the goal (SCSMEX Science Working Group, 1995) with shipboard measurements, Autonomous Temperature Line Acquisition System (ATLAS) moored array, and drifters. During SCSMEX, the hydrographic data set included over 1700 CTD (Figure 2) and mooring stations (Chu et al, 2001, 2004b). The hydrographic data collected during the SCSMEX IOP went through quality control procedures such as min-max check (e.g., disregarding any temperature data less than -2^{o}C and greater than 40^{o}C), error anomaly check (e.g., rejecting temperature data deviating more than 7^{o}C from climatology), ship-tracking algorithm (screening out data with obvious ship position errors), max-number limit (limiting a maximum number of observations within a specified and rarely exceeded space-time window), and buddy check (rejecting contradicting data). The climatological data used for quality control are depicted in Chu et al. (1997a, b). After the quality control, the SCSMEX oceanographic data set contains 1742 conductivity-temperature-depth (CTD) and mooring stations. The majority of the

CTDs were nominally capable of reaching a maximum depth of 2000 m. SCSMEX provided a unique opportunity to evaluate ocean nowcast system (Chu et al., 2004b) and forecast system (Chu et al. 2001).

3. Ocean Nowcast System

MODAS is one of the present U.S. Navy standard nowcast system for producing three-dimensional grids of temperature and salinity. It is a modular system for ocean analysis and is built from a series of FORTRAN programs and UNIX scripts that can be combined to perform desired tasks (Chu et al., 2004b). MODAS was designed to combine observed ocean data with climatological information to produce a quality-controlled, gridded analysis field as output (Figure 3). The analysis uses an optimal interpolation (OI) data assimilation technique to combine various sources of data (Fox et al., 2002).

Chu et al. (2004b) evaluated MODAS using the SCSMEX data. The errors for temperature and salinity nowcast have a Gaussian-type distribution with zero mean for temperature and -0.048 ppt for salinity and with standard deviation (STD) of 0.98^{o}C for temperature and 0.22 ppt for salinity. This result indicates that MODAS usually under-predicts the salinity. The RMSE of temperature between the MODAS and SCSMEX data increases rapidly with depth from 0.55^{o}C at the surface to 1.72^{o}C at 62.5 m and then reduces with depth to near 0.03^{o}C at 3000 m deep. The RMSE of salinity between the MODAS and the SCSMEX data has a maximum value (0.347 ppt) at the surface. It decreases to a very small value (0.009 ppt) at 3000 m. Interested readers are referred to Chu et al. (2004b).

4. Ocean Forecast System

NCOM, a popular ocean forecast system, is based on two existing circulation models, POM and the Sigma/Z-level Model (SZM). NCOM has a free surface and is based on the primitive equations and the hydrostatic, Boussinesq, and incompressible approximations. Horizontal mixing is provided through either grid-cell Reynolds number or the Smagorinsky scheme. The Mellor Yamada Level 2 or 2.5 turbulence models provide for vertical mixing parameterization. The model uses an Arakawa C grid, is leapfrog in time, and uses second-order centered spatial finite differences. The propagation of surface waves and vertical diffusion are treated implicitly. NCOM has a curvilinear horizontal grid and the vertical grid uses sigma coordinates for the upper layers and z-level (constant depth) coordinates for the lower layers.

Chu et al. (2001) evaluated POM using the SCSMEX data. During the evaluation, the POM was implemented in the domain (98.84^o-121.16^{o}E, 3.06^{o}S-25.07^{o}N) covering the whole SCS with horizontal resolution of 0.179^o by 0.175^o (approximately 20 km resolution) and vertical resolution of 3 sigma levels. The model uses realistic bathymetric data from the Naval Oceanographic Office Digital Bathymetry Data Base.

Similar to MODAS, the errors of POM also have a Gaussian-type distribution with zero mean for temperature and -0.022 ppt for salinity. The RMSE for temperature is 0.2^{o}C at the surface, increases with depth to a maximum value of 1.2^{o}C (May 98) or of 1.4 (June 98) at 50-100 m depth, and then decreases with depth to a minimum value of 0.3^{o}C (May 98) or 0.5^{o}C at 500 m. The mean RMSE is around 0.6^{o}C. The RMSE for salinity is near zero at the surface, increases with depth to a maximum value of 0.22 ppt (May 98) or of 0.21 ppt (June 98) at 25-75 m depth, and then reduces with depth to a

minimum value of 0.03 ppt at 500 m. The mean RMSE is around 0.06 ppt. The interested readers are referred to Chu et al. (2001).

5. Weapon Acoustic Preset Program

5.1. General Description

WAPP is an automated, interactive program designed to provide the fleet with an onboard means of generating acoustic presets for multiple variants of Mk 48 torpedoes and visualizing their performance. Developed by Naval Undersea Warfare Center (NUWC), Division Newport, RI, it consists of several elements including a graphical user interface (GUI) for entering various data, a computational engine for generating acoustic performance predictions, and various forms of output (Chu et al., 2004a, 2006).

The types of input data necessary include tactical (such as tactic type and depth zone of interest), target (such as acoustic and Doppler characteristics), weapon (such as type, mod, and active or passive acoustic mode), and environmental information. To input the environmental information, the user selects the “environment” pull-down menu of the GUI to bring up the Environmental Data Entry (EDE) window. This window, shown in Figure 4, allows the entry of water column parameter profiles (such as temperature, salinity, sound speed, and volume scattering strength) for a specified latitude and longitude. Other environmental input entered via the EDE consists of sea surface conditions (wind speed, wave height, and sea state) and bottom conditions (depth and type). Operationally the environmental data is received from the Sonar Tactical Decision Aid.

5.2. WAPP Presetting Process

Once the necessary information is input (or default values are selected), WAPP is ready to undergo the presetting process. This process is begun by using the "compute" pull-down menu of the GUI and is outlined in Figure 5. The first step is to establish a valid set of search depth (SD) and search angle (SA) combinations. The program then invokes a search angle selection algorithm to identify the optimal pitch angle for each search depth. Next, the computational engine traces, in a series of time steps, a fan of rays that bound the torpedo beam pattern for each resulting SD/SA combination (Amezaga, 2006). A signal excess computation is performed and mapped to a gridded search region at each time step using the monostatic, active sonar equation for the reverberation limited case,

$$\mathrm{SL} - 2\mathrm{TL} + \mathrm{TS} - \mathrm{RL} - \mathrm{DT} = \mathrm{SE}, \tag{1}$$

where SL is the active sonar source level, TL is the two-way transmission loss between the sonar and the target, TS is the target strength, RL is the reverberation level, and DT is the detection threshold. The signal excess map is used to determine the effectiveness ratio (the fraction of the prosecutable search region with signal excess greater than 0 dB, also called area coverage) and laminar distance (the location of signal excess center of mass). WAPP then ranks the SD/SA combinations based on these computations (along with some other mitigating factors) and makes a recommendation as to the best preset for the given scenario.

In solving equation (1), the SL, DT, and TS terms are based on properties of the sonar system and target involved, so they are selected by the program or entered by the user, as is the case for TS. The TL and RL terms are computed using a range-independent, ray theory propagation model that accounts for geometric spreading,

refractive effects, volumetric effects, and boundary interactions with the ocean surface and bottom. The vertical sound speed profiles used by the ray tracing model are calculated by WAPP from the temperature and salinity profiles using the equation proposed by Chen and Millero (1977). Geometric spreading and refractive losses are determined using the transmission loss equation derived using ray theory

$$TL = 10\log\left(\frac{R_k\left|\frac{\partial R_k}{\partial \theta_o}\sin\theta_k\right|}{\cos\theta_o}\right), \qquad (2)$$

where R_k is the horizontal range at some position downrange, θ_o is the initial angle of the ray, and θ_k is the angle of the ray at range R_k.

5.3. Ranked List-Set

To offer a means of user interaction, the output of WAPP is in the form of a ranked list-set of search depths, pitch angles, laminar distances, and effectiveness values. This allows the user to view all SD/SA combinations, not just the recommended one, and select the most appropriate one for the situation. The list-set is, therefore, a list of possible presetting choices from which the operator can choose. In addition, the ray traces and signal excess maps are viewable using the GUI's "acoustic coverage" pull-down menu. These forms of output provide a visual interpretation of the acoustic performance of the torpedo, including boundary interactions and refraction effects.

Since the propagation model uses ray theory, it has all the shortcomings associated with it, such as being limited to higher frequencies. In this case, this is an acceptable condition because the Mk 48 torpedo has a suitably high operating frequency. Another deficiency of ray theory is the poor handling of shadow zones due to the

assumption that no acoustic energy leaks out of the ray tube. This is also acceptable because, from a weapon presetting standpoint, it is unrealistic to direct a torpedo to home in on a target in a shadow zone, so an accurate description of the sound field there is not necessary. Finally, ray theory has the issue of causing energy to approach infinity at caustics and turning points. This last concern is mitigated through the use of a caustic correction that modifies the propagation equations, thereby avoiding the case where the denominator becomes zero, and approximates the signal level near the caustic.

Because the propagation model is range-independent, it assumes cylindrical symmetry, meaning it does not have range-varying properties. For example, sound speed is a function of depth only and, since bathymetry is absent, a flat, homogeneous bottom is used. Therefore, the resulting ray traces are assumed to be valid for any direction from the source location, as the model environment looks the same down any bearing (Etter, 1991; Medwin and Clay, 1997). This is not ideal for determining accurate sound propagation characteristics, especially in regions where the oceanography changes rapidly with horizontal distance, and could affect the weapon presets. Under less variable conditions, this shortcoming would probably have little or no affect on the weapon presets, as the typical Mk 48 torpedo engagement would only involve a few kilometers of ocean. Regardless, there is an effort currently underway to utilize the Comprehensive Acoustic Sonar Simulation for range-dependent performance predictions for torpedo presetting. The assumption of range independence is consistent with the large number of areas where there is little to no bathymetric variation over torpedo detection ranges and also with cross-slope predictions in more variable environments, and so provides a

reasonable assessment of the importance of satellite altimetry data using the current weapon system.

6. Relative Difference

The acoustic area coverage (AC) for different SD/SA combination is selected as the key output for the evaluation. Since the SCSMEX (T, S) profiles are treated as 'ground truth' environmental data, the WAPP output with the SCSMEX data is considered as the **reference solution** for the weapon system. Absolute relative differences (RD) in the key WAPP output between using the SCSMEX data and the ocean nowcast/forecast data,

$$RD_M = \frac{|AC_M\text{-}AC_O|}{AC_M}\ , \quad RD_P = \frac{|AC_P\text{-}AC_O|}{AC_P}, \qquad (3)$$

can be treated as the deviation from the WAPP reference solution. The less the RD_M (or RD_P), the better the environmental input from the nowcast/forecast systems to WAPP. Here, the subscripts 'M' denotes MODAS, 'P' denotes POM and 'O' denotes observation (i.e., the SCSMEX data).

The presetting process has generated pairs of list-sets in which some SD/SA combinations were the same and others were different. The list-set can be thought of as a list of presetting choices; the choices on one list sometimes matched those on the other list and sometimes not. The instances in which WAPP produce different SD/SA combinations for a profile pair are the cases in which an actual engagement would have greater potential for a different outcome because, given these different choices, the torpedo would not be searching at the same depth, looking at the same search angle, or both. Determining the sensitivity of WAPP to input differences in these cases is

important because of the potential for weapon effectiveness to be affected. The thing to remain aware of here is that the actual environment is whatever it is, regardless of differences in the SCSMEX-MODAS (or SCSMEX-POM) pair profiles. In the cases where the same SD/SA combinations (same choices) are generated for the pair profiles (SCSMEX-MODAS or SCSMEX-POM), the outcome of the engagement would be very similar, subject to other targeting considerations, because the same presets and environment are involved.

Figure 6 depicts two torpedo engagement simulations conducted by the Naval Undersea Warfare Command (NUWC) – Newport, where there is a 0.2 relative difference of acoustic coverage in the torpedo acoustic cone. Each dot (in red) is a probable contact until the acoustic cone of the torpedo passes over the dot. The dot turns yellow when the torpedo has a detection opportunity. The torpedo then enters into its detection, acquisition, and verification phases. If a dot remains in the acoustic cone long enough to complete the detection, acquisition, and verification phases, the torpedo will likely enter homing with a green dot.

In the first case (Figure 6a), 94.2% of tracks enter the acoustic cone and 46.7% enter homing with an overall coverage score of 47.7 %. In the second case (Figure 6b), when the acoustic coverage was reduce by 20%, 89.6% of tracks enter the acoustic cone and only 16.3% enter homing with an overall coverage score of 33.8%. In other words, a relative difference of 0.2 leads to an engagement with 1/3 as likely to the mission success. So, a relative difference of 0.2 is large enough to change an engagement. A regression curve (not shown here) that is bound by the by first and second case infers that

a RD between 0.10 and 0.15 would yield an overall coverage score between 47.7% and 33.8%.

7. Sensitivity of WAPP to Ocean Model Uncertainty

7.1. Procedure of the Test

Figure 7 shows the procedures of the evaluation. The SCSMEX-MODAS and SCSMEX-POM data pairs (temperature and salinity profiles) are taken as environmental input into WAPP. WAPP then calculates the sound speed from the respective temperature and salinity grid point pairs. The same default values for volume scattering strength and surface and bottom conditions were used for each run. This procedure is repeated for the SCSMEX-MODAS (or SCSMEX-POM) profiles from April to June 1998 (SCSMEX Intensive Observation Period) in the SCS for the five tactical scenarios. The tactical scenarios are selected using the Acoustic Preset GUI (Figure 4). The five tactical scenario selected were high Doppler anti surface warfare (HD ASUW), low Doppler anti surface warfare (LD ASUW), low Doppler shallow anti submarine warfare (LD shallow ASW), high Doppler shallow anti submarine warfare (HD deep ASW), and low Doppler shallow anti submarine warfare (LD deep ASW). Shallow ASW is defined as maximum target depth of 213 m, and deep ASW is define as maximum target depth of 396 m.

The WAPP output is a ranked list-set of different SD/SA combination and acoustic coverage generated for the aforementioned tactical scenario between using the respective modeled (MODAS or POM) and observed (SCSMEX) temperature and salinity fields. A configuration management program which included a statistical

software package was employed to compare the generated list set. Any differences in the output (RD) were attributed to the ocean model uncertainty.

7.2. Statistical Characteristics of RD_M and RD_P

The errors in ocean nowcast system (e.g., MODAS) and forecast system (e.g., POM) may have an effect on the output of WAPP, depending on the sensitivity of WAPP to changes in input. The cases highlighted here have fairly significant differences in the temperature, salinity, and sound speed fields.

In each of the five scenario histograms for MODAS, the frequency has peak at RD_M = 0.10 (or 0.15). For HD deep ASW, the frequency of different SD/SA combinations is very small for small RD_M (Figure 8), increases with RD_M to 150 at RD_M = 0.10 (162 for RD_M = 0.15), and then decreases with RD_M to 8 at RD_M = 0.20 (6 at RD_M = 0.25). In other words, the peak frequency is at RD_M = 0.15.

Similarly, in each of the five scenario histograms for POM, the frequency has peak at RD_P = 0.10. For HD deep ASW, the frequency of different SD/SA combinations is very small for small RD_P (Figure 9), increases with RD_P to 282 at RD_P = 0.10, and then decreases with RD_P to 25 at RD_P = 0.15, and to 2 at RD_P = 0.20. In other words, the peak frequency is at RD_P = 0.10.

The mean RD_M and RD_P (Figure 10) have the following features: (a) the mean RD_P is always less than RD_M for all the five scenarios; (b) they are smaller for the three ASW scenarios than for the two ASUW scenarios; and (3) RD_M is nearly 0.2 and RD_P is about 0.12 for HD and LD ASUW scenarios. The highest mean RD_M (0.1983) and RD_P (0.1273) are for the high Doppler ASUW tactics. The lowest mean RD_M is 0.0966 are for the low Doppler deep ASW tactics. The lowest mean RD_P (0.0758) is for the low

Doppler deep and shallow ASW tactics. Smaller values of relative difference using POM than using MODAS ($RD_P < RD_M$) in all five tactics may imply that the ocean forecast system (physical model) outperforms than the ocean nowcast system (statistical model) in the WAPP prediction for torpedo Mk-84.

7.3. Probability of RD over Thresholds

The probabilities of RD being greater than 0.1 and 0.15,

$$\mu_1 = \Pr ob\,(\mathrm{RD} > 0.1), \quad \mu_2 = \Pr ob\,(\mathrm{RD} > 0.15), \tag{4}$$

are used for the model evaluation. From the preceding discussion it is apparent that, in some of the scenarios, WAPP output was quite sensitive to changes in input environmental fields, such as MODAS and POM versus SCSMEX. For MODAS, the μ_1 values range from 0.2375 (low Doppler Deep and Shallow ASW) to 0.81 (high Doppler ASUW) and the μ_2 values range from 0.015 (low Doppler deep ASW) to 0.71 (high Doppler ASUW) (see Table 1). For POM, the μ_1 values vary from 0.03 (low Doppler Deep and Shallow ASW) to 0.55 (low and high Doppler ASUW) and the μ_2 values vary from 0.0025 (high Doppler deep ASW) to 0.2121 (high Doppler ASUW) (see Table 2). This suggests that the sensitivity of WAPP is extremely variable and, therefore, so is the chance of affecting the outcome of an engagement. Based on this sensitivity analysis, the ocean nowcast/forecast systems contributed 50% (POM) to 80% (MODAS) chance of having a different engagement outcome in the ASUW scenarios (once again, assuming 0.1-0.15 is enough of a relative difference in area coverage to change the outcome), but 4% (POM) to 40% (MODAS) chance of having a different engagement outcome in the ASW scenarios.

For each scenario, the values of (μ_1, μ_2) are greater using MODAS (Figure 11) than using POM (Figure 12). In each model (MODAS or POM), the values of (μ_1, μ_2) are greater for the ASUW scenarios than for the ASW scenarios. For example, μ_1 with POM is 0.03-0.06 for the three ASW tactical scenarios; on the other hand, μ_1 with MODAS is 0.24-0.44 for the three ASW tactical scenarios.

8. Conclusions

Usefulness of ocean nowcast system (MODAS) and forecast system (POM) for the naval undersea warfare is evaluated using the Weapon Acoustic Preset Program with observational (*T*, *S*) data collected from SCSMEX. The overall value of ocean nowcast/forecast systems is assessed by its effect on the outcome of actual engagement, or weapon effectiveness. The value could then be based on whether or not the outcomes were affected positively, which in an ASW (or ASUW) engagement typically means the torpedo hit the target versus missed it. In this study, torpedo performance in the real world was not readily quantifiable because, although the SCSMEX observational data is certainly closer to the actual environmental conditions, there is no way to relate the weapon (i.e., torpedo) performance predictions to the expected real world performance. The only real world performance assertion is made to single out the different SD/SA combinations for the sensitivity analysis that the engagement would have been very similar if the weapon is assigned the same presets.

This study shows that the full physical ocean forecast system (POM) outperformed the statistical nowcast system (MODAS) in all 5 tactical scenarios. The ocean forecast system (POM) had smaller relative differences in acoustic coverage than the ocean nowcast system (MODAS) comparing to the WAPP with observational T, S

profiles from SCSMEX. The sensitivity analysis also confirmed that the probability decreases with increasing tactic depth that is in agreement with earlier study (Chu et al., 2006).

The scenarios in which WAPP is the most sensitive are the ones where the model input (MODAS or POM) differed significantly from observational input (SCSMEX), especially in the depth zone of interest for the given tactic (ASW or ASUW). The environmental model uncertainty causes uncertainty in the SSP characteristics, which in turn leads to large differences in the sound propagation predictions made by WAPP for the ocean environmental model and observational fields, and thus to large relative differences in area coverage.

To quantify the effect on weapon effectiveness, a two-part study needs to be conducted. Part 1 would compare the output of WAPP using modeled (e.g., nowcast/forecast systems) and in situ measurements of the local environment (e.g., SCSMEX here). The in situ measurements could be performed by any number of assets, such as a U. S. Navy ship during an exercise or a research vessel, although the area should be one with large variability, such as in the Gulf Stream or Kuroshio Current, to obtain the most benefit from the ocean nowcast/forecast. Of course, as with any experiment involving in situ measurements, the data set will be much smaller than the one used in this study.

With this type of comparison, any differences in WAPP output could be correlated to the torpedo's predicted real world performance and, therefore, so could be the benefit of any new model development. For example, if the predicted performance is similar for the MODAS field with the new development and the in situ data, but the

performance differed appreciably for the MODAS field without such a development, the new model development would be quite valuable. On the other hand, the new model development would be deemed as being less beneficial. Of course, the predicted performance is still not real world performance, however.

To even better assess the effect of the ocean nowcast/forecast systems on weapon effectiveness, Part 2 would need to include simulations of torpedo engagements. The Weapons Analysis Facility at NUWC, Division Newport has the capability to simulate engagements using torpedo hardware-in-the-loop and a high fidelity virtual environment. Using the Weapon Analysis Facility and presets generated by the ocean nowcast/forecast fields and in situ data in Part 1, many virtual torpedo engagements could be conducted to examine the effects of the different nowcast/forecast fields on virtual performance. This could be done for any number of scenarios, by alternately using presets generated by each of the environmental inputs to WAPP and then comparing the ratios of hits to misses for the virtual engagements.

This experiment introduces an operational element by enabling the presets to be chosen by an operator for each engagement. It would also eliminate the need to use the relative difference in area coverage and the associated uncertainty in the threshold that produces changes in engagement outcome. This is because the proposed metric, the hit-miss ratio, is not a prediction of performance (like area coverage) but, rather, a direct assessment of it (once again, in a virtual environment). Aside from the cost and logistics prohibitive alternative of putting many torpedoes in the water, an experiment such as this would provide the next best analysis of the value-added ocean nowcast/forecast systems with regard to torpedo effectiveness.

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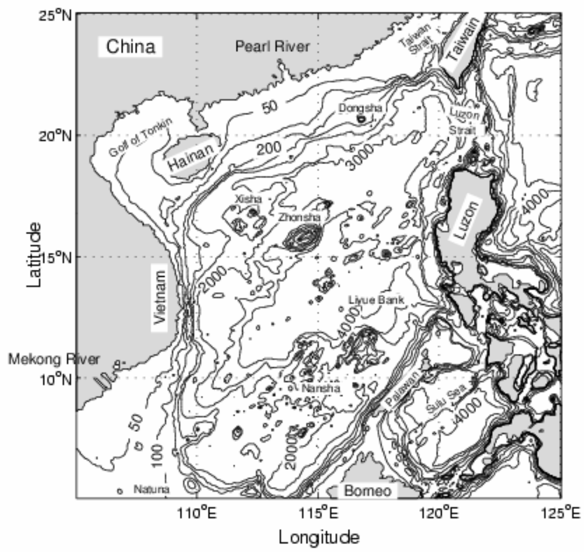

Figure 1. Geography and isobaths showing the bottom topography of the South China Sea. Numbers show the depth in meter.

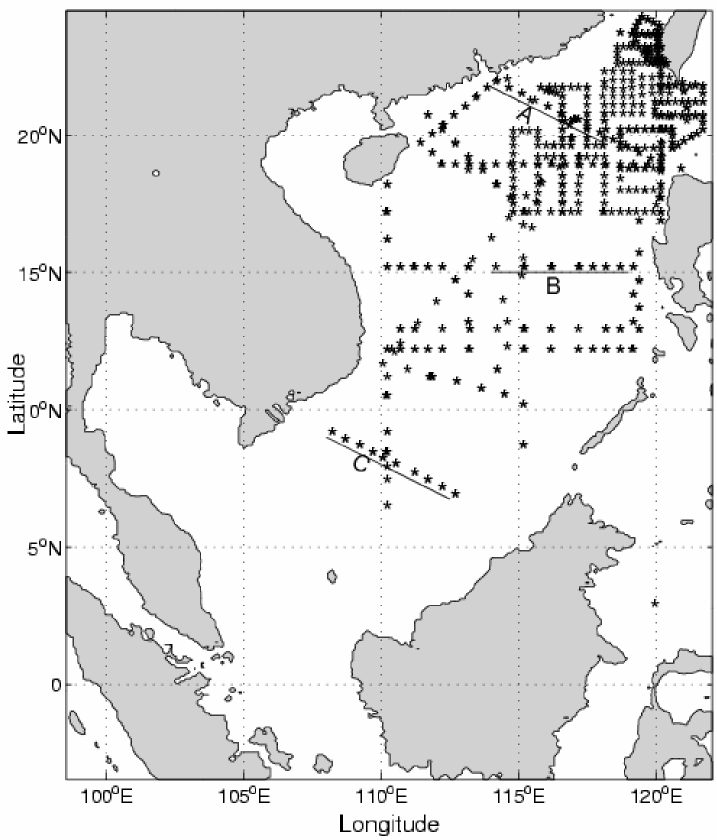

Figure 2. The SCSMEX CTD stations.

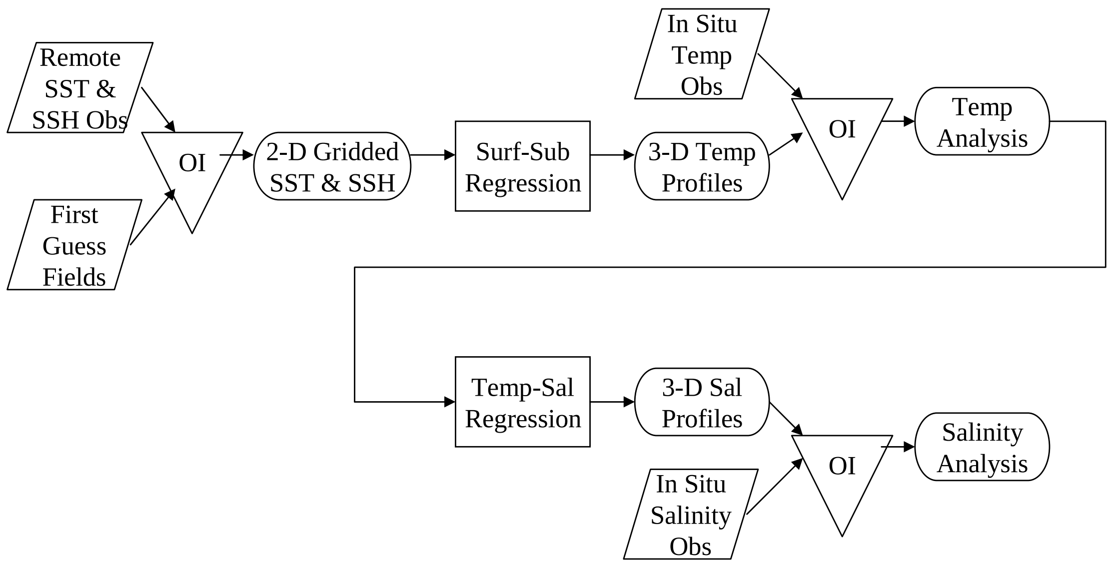

Figure 3. Flow chart of MODAS operational procedure.

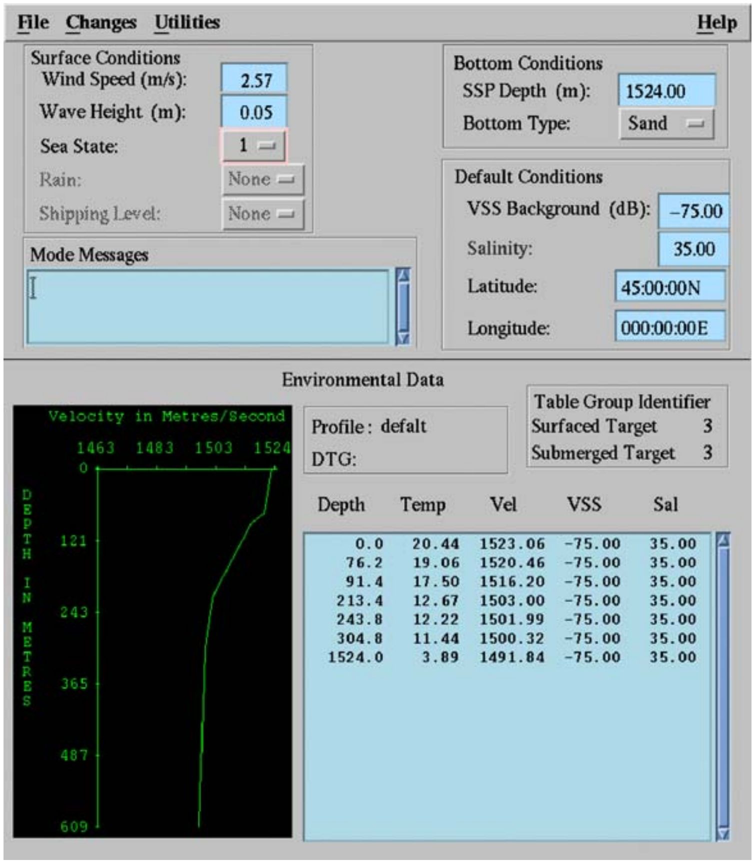

Figure 4. Weapon acoustic preset module display.

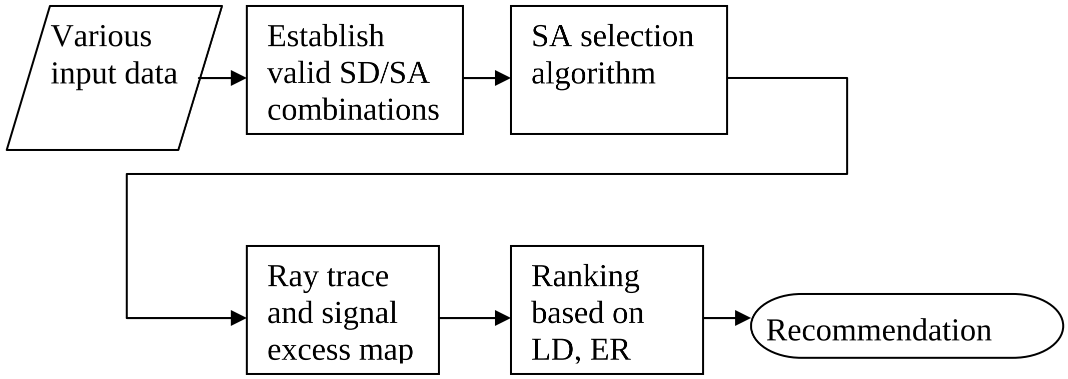

Figure 5. Flow chart of WAPP presetting procedure.

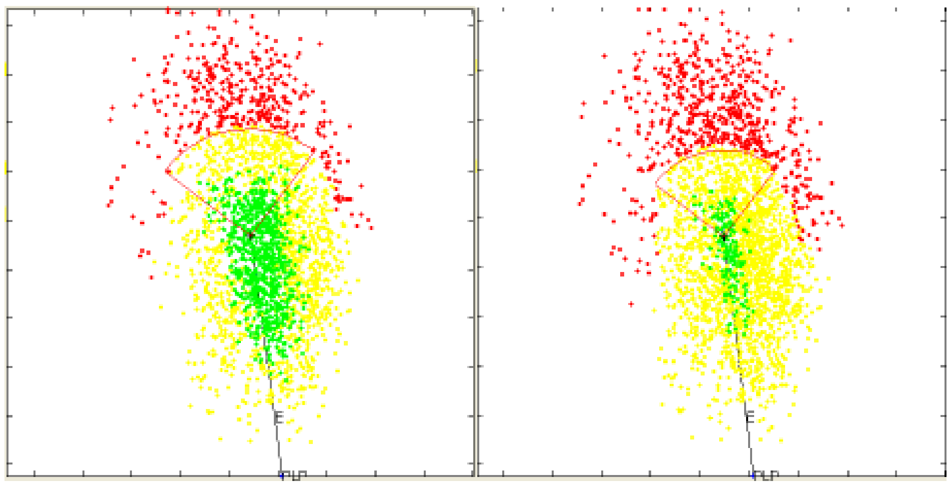

Figure 6. Horizontal acoustic coverage for a torpedo: (a) with a typical acoustic cone (left panel), and (b) with a 20% reduced acoustic cone (right panel).

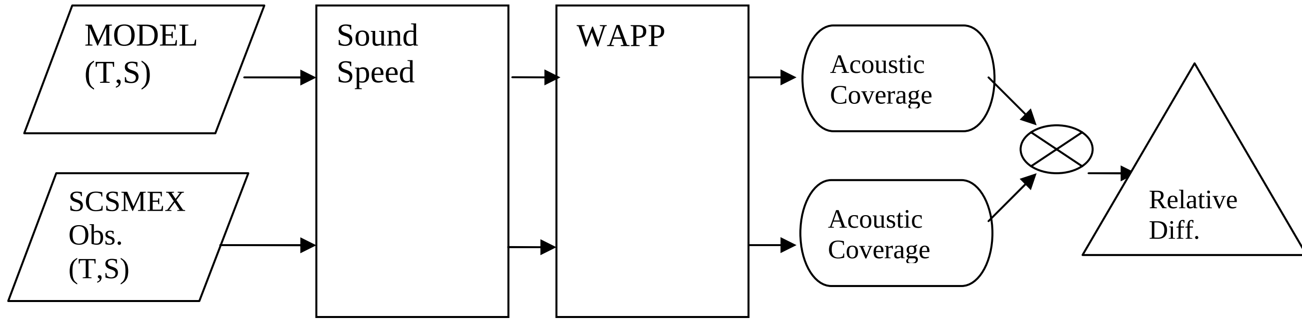

Figure 7. Procedure of the ocean nowcast/forecast systems using WAPP.

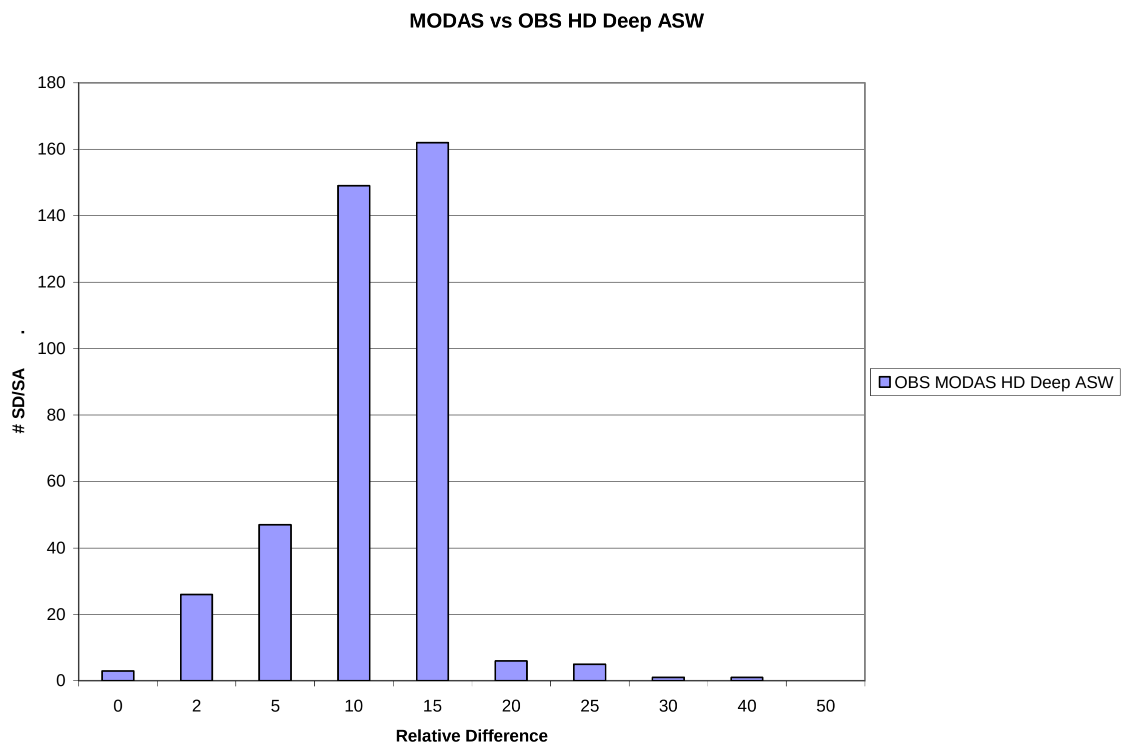

Figure 8. Histogram of RD_M (in %) for HD deep ASW scenario (mean value: 0.113; standard deviation: 0.0488).

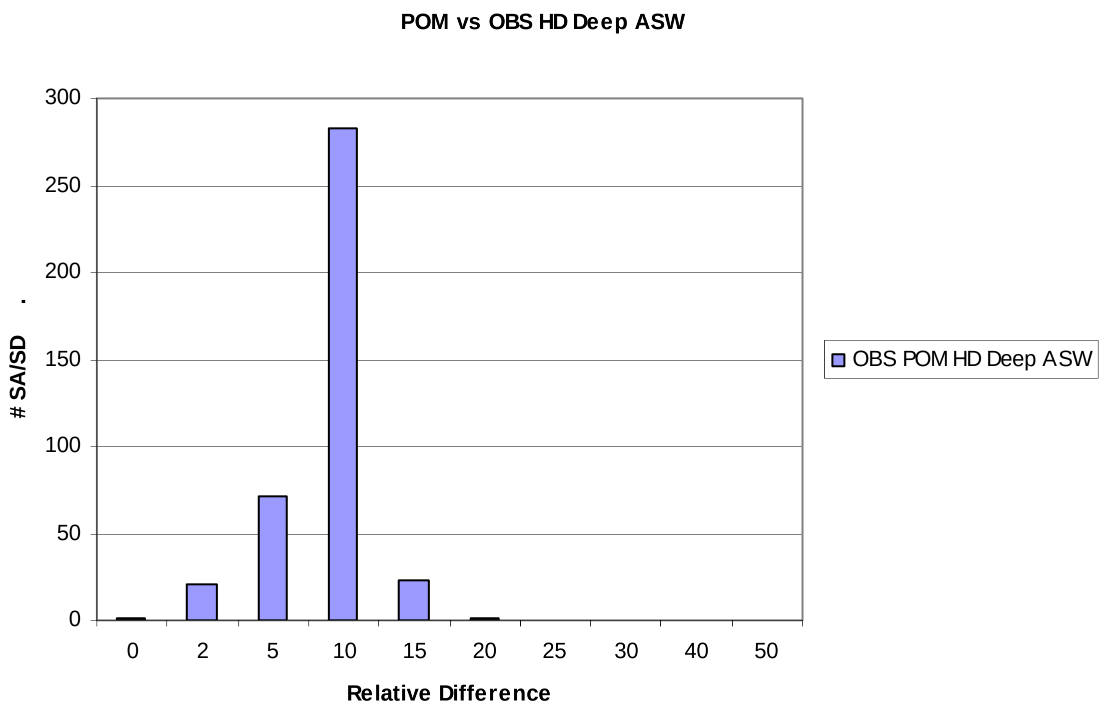

Figure 9. Histogram of RD_P (in %) for HD deep ASW scenario (mean value: 0.0898; standard deviation: 0.0295).

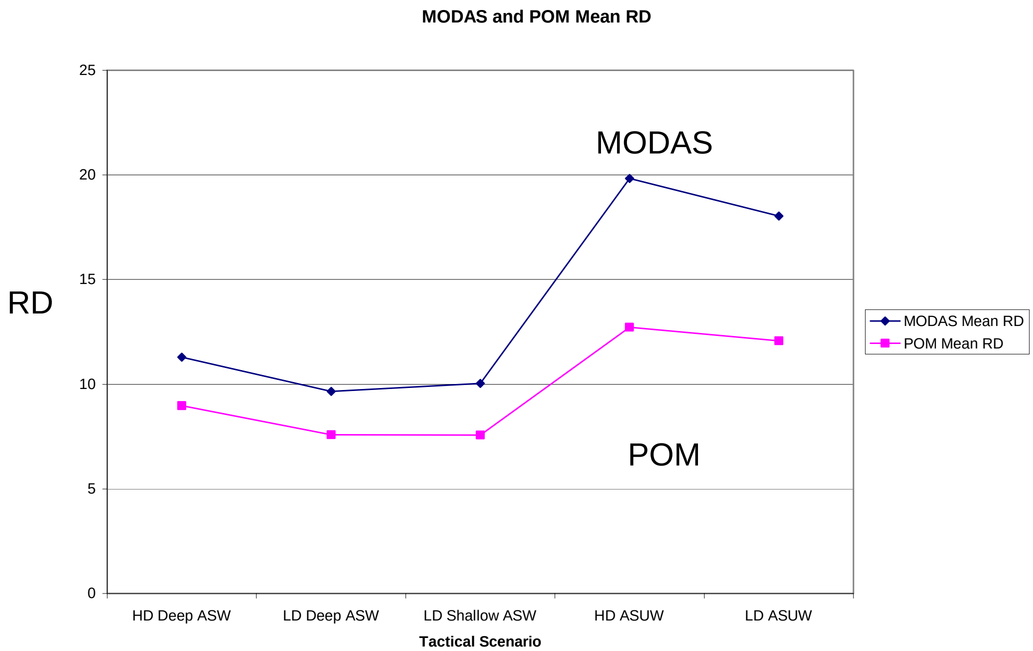

Figure 10. Mean RD_M and RD_P (in %) for five scenarios.

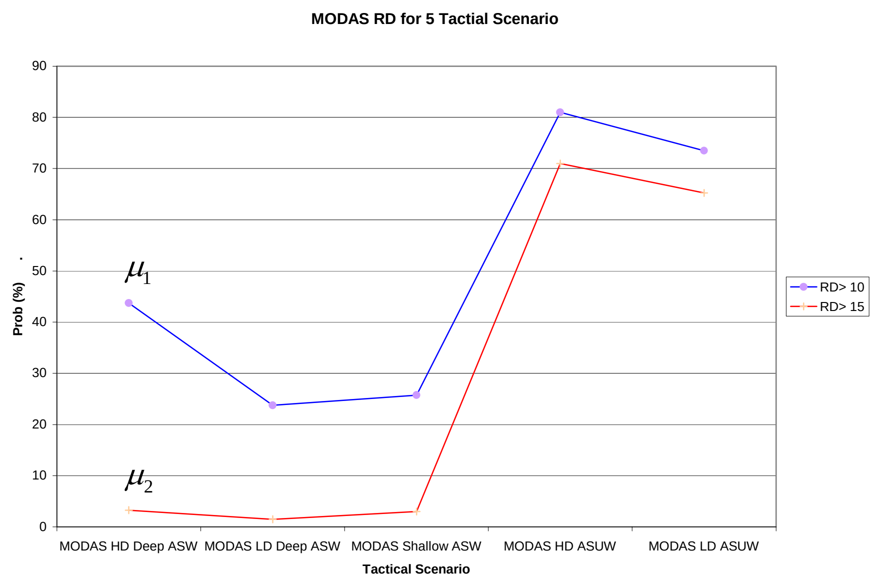

Figure 11. Two probabilities (μ_1, μ_2) (in %) of RD_M for the five tactical scenarios.

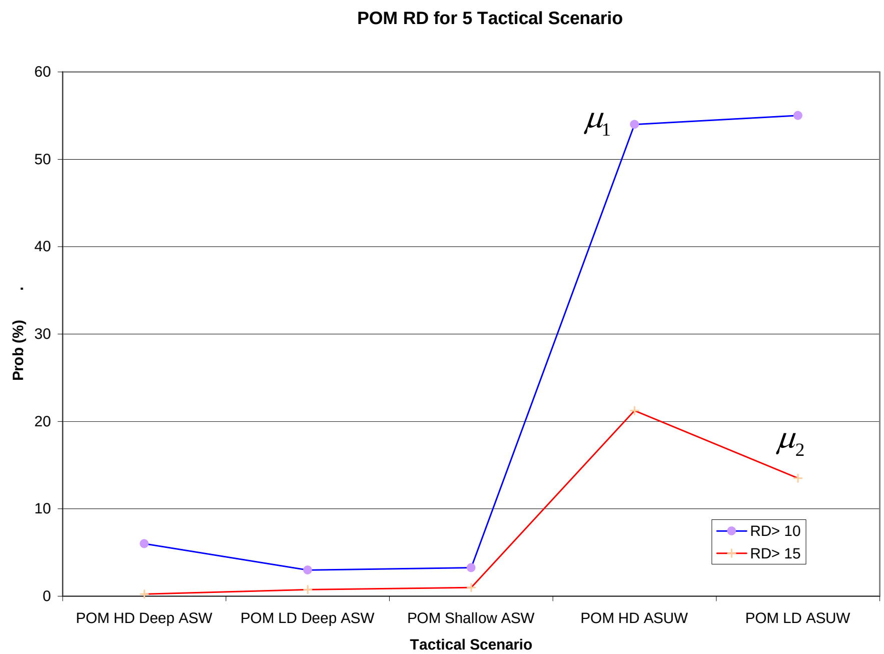

Figure 12. Two probabilities (μ_1, μ_2) (in %) of RD_P for the five tactical scenarios.

Table 1. Overall sensitivity of weapon acoustic preset to MODAS in the South China Sea simulation.

Scenario	***Prob (RD_M>0.1)***	***Prob(RD_M>0.15)***	***Mean RD_M***	***Std Dev of RD_M***
HD Deep ASW	0.4375	0.0325	0.113	0.0488
LD Deep ASW	0.2375	0.015	0.0966	0.0441
LD Shallow ASW	0.2575	0.03	0.1004	0.0476
HD ASUW	0.81	0.71	0.1983	0.0789
LD ASUW	0.735	0.6525	0.1804	0.0776

Table 2. Overall sensitivity of weapon acoustic preset to POM in the South China Sea simulation.

Scenario	***Prob (RD_P>0.1)***	***Prob(RD_P>0.15)***	***Mean RD_P***	***Std Dev of RD_P***
HD Deep ASW	0.06	0.0025	0.0898	0.0295
LD Deep ASW	0.03	0.0075	0.0759	0.0356
LD Shallow ASW	0.0325	0.01	0.0758	0.0362
HD ASUW	0.54	0.2121	0.1273	0.0579
LD ASUW	0.55	0.1325	0.1208	0.0551